Japanese R&D Program for Making Safety Case for Geological Repository

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Abstract

The Japan Nuclear Cycle Development Institute (JNC), successor to the Power Reactor and Nuclear Fuel Development Corporation (PNC) as of 1st October 1998, completed a second progress report (referred to as H12) on research and development for geological disposal of high-level waste (HLW) in Japan and submitted it to the Atomic Energy Commission (AEC) of Japan in November 1999. H12 documents progress made since the publication of the first progress report (H3) in 1992 and will be presented to the Japanese Government for assessment by the year 2000. The purpose of the work was specified in a report published in April 1997 by the Advisory Committee on Nuclear Fuel Cycle Backend Policy of the AEC entitled "Guidelines on Research and Development Relating to Geological Disposal of High-Level Radioactive Waste in Japan" (hereafter the AEC Guidelines). The primary objective of H12, as specified in the AEC Guidelines, is to present an outline of "the technical reliability of geological disposal in Japan". It should also provide input for the siting and regulatory processes, which will be set in motion after the year 2000.

Demonstration of technical reliability relies on two fundamental principles. Firstly, that a properly sited and designed repository with a robust engineered barrier system is intrinsically safe because it eliminates potential major disruptive processes and ensures that any releases of radionuclides in the far future will have no significant health effects. The second principle is that a detailed, realistic-conservative safety assessment of the engineered and natural barrier system can demonstrate a wide margin of safety for the proposed disposal concept in Japan. This paper presents an executive-level description of the application of these two principles to the safety case for the Japanese HLW program.

Introduction

In Japan, as outlined in the overall high-level radiaoactive waste (HLW) management program defined by the Atomic Energy Commission (AEC) of Japan (AEC, 1994) , the HLW separated from spent nuclear fuel at reprocessing plants will be immobilized in a glass matrix and stored for a period of 30 to 50 years to allow cooling. It will then be disposed of in a deep geological formation (geological disposal). Pursuant to the overall HLW management program, an organisation with responsibility for implementing HLW disposal will be established around the year 2000. This will be followed by site selection and characterisation, demonstration of disposal technology, establishment of the necessary legal infrastructure, relevant licensing applications and repository construction, with the objective of starting repository operation by the 2030s and no later than the mid 2040s.

The HLW disposal program is currently in the research and development (R&D) phase and the Japan Nuclear Cycle Development Institute (JNC) has been assigned as the leading organization responsible for R&D activities. The aim of the R&D activities at the current stage is to provide a scientific and technical basis for the geological disposal of HLW in Japan, and promote understanding of the safety concept not only in the scientific and technical community but also by the general public. As one of the features of the R&D program, its progress is documented at appropriate intervals, with a view to clearly determining the level of achievement of these programs and to promote understanding and acceptance of the geological disposal strategy by the general public. As a major milestone, the Power Reactor and Nuclear Fuel Development Corporation (PNC, now JNC) submitted a first progress report, referred to as H3 (PNC, 1992), in September 1992. H3 summarized the results of R&D activities up to March 1992 and identified priority issues for further study.

The second progress report (entitled H12) in Japanese (JNC, 1999a; 1999b; 1999c; 1999d), which documents progress made since the publication of the H3, submitted to the AEC in November 1999. The purpose of the work was specified in a report published in April 1997 by the Advisory Committee on Nuclear Fuel Cycle Backend Policy (ACNFCBP) of the AEC entitled "Guidelines on Research and Development Relating to Geological Disposal of High-Level Radioactive Waste in Japan" (hereafter the AEC Guidelines) (ACNFCBP, 1997). The objective of the H12 is to demonstrate more rigorously and transparently the technical feasibility and reliability of the specified disposal concept. It should also provide input for the siting and regulatory processes, which will be set in motion after the year 2000.

Strategy for Making the Safety Case

The concept of geological disposal in Japan is similar to that in other countries, being based on a multibarrier system which combines the natural geological environment with engineered barriers. The approach for development of a disposal system concept has targeted neither a particular type of rock nor a particular area. However, particular consideration is given to the long-term stability of the geological environment, taking into account the fact that Japan is located in a technically active zone. The wide range of geological environments throughout Japan was also considered. Due to Japan's complex geology, an engineered barrier system (EBS) with sufficient margins in its isolation functions to accommodate a wide range of geological environments was developed. The major component of overall barrier performance of the disposal system is borne by the near-field, while the remainder of the geosphere serves to reinforce and complement the performance of the EBS. This massive EBS was introduced to ensure long-term performance of the disposal system for a wide range of geological environments. Thus, the basic concept in Japan is to construct an EBS, that in a stable geological environment has sufficient margins of error in long-term isolation of the waste to accommodate a range of geological conditions and their potential future states (Masuda et al., 1998). The reference layout of the EBS involves either axial, horizontal emplacement in a tunnel or vertical emplacement in a pit, of vitrified waste encapsulated in a thick steel overpack which is surrounded by highly compacted bentonite. In this paper, the axial, horizontal emplacement method is assumed for the reference EBS layout.

The safety concept assumes that disruptive events can be excluded by site selection. The remaining geological environments identified as having favorable characteristics for the disposal system provide the basis for repository design. If the safety functions of the geological disposal system are assured, minor amounts of radioactivity released from the EBS will further decay and concentrations will be reduced by dilution during the long migration period in the geosphere. HLW disposal can thus be realized in such a way that no significant detrimental influence is exerted on either man or his environment.

Thus, the basic functions of the repository design provide intrinsic safety in a long-term passive management mode. To support this safety concept, it is important for R&D activities to focus on the natural system attributes which optimize EBS performance including relative tectonic stability, low groundwater flux, favorable geochemistry and a low risk of disruptive events. Then, performance assessment should be conducted for the repository design taking alternative future evolutions of the system into account in order to illustrate the robustness of its intrinsic safety features.

Confidence in the Intrinsic Safety of the Repository Concept

In order to increase the confidence in the technical feasibility of the deep geologic HLW disposal concept, the H12 report must provide more detailed analysis to demonstrate how the intrinsic safety functions of the repository design supported by quality assurance and careful site selection can provide a robust degree of safety. Demonstrating that the H12 concept is a qualified and intrinsically safe disposal system concept includes:

- Demonstration of the existence of geological environments which are stable for a long-time and provide favorable conditions supporting EBS performance and the radionuclide retardation capacity of the geosphere, and
- Illustrating an appropriate design for containment and retardation of radionuclides in the EBS for a wide range of geological environments.

In addition, the H12 report must improve the process for implementing and provide results of performance assessments to estimate the long-term reliability of the repository system for a number of different settings and geologic systems.

Two key areas in which the H12 report provides more reliability and more confidence in the geologic disposal concept than the H3 approach are:

- Its implementation of a systematic approach for scenario development along with a logical audit trail; and
- More realistic modeling and a more robust database for near-field performance oriented toward the specific characteristics of the geological environment of Japan.

In order to meet the above requirements, current R&D work focuses on development of detailed and realistic near-field models and on improving the understanding of key processes and corresponding databases, taking into account a wide range of geological conditions. In JNC's R&D program, three major areas of research have been conducted. These areas are 1) investigation of processes and features of the geological environments considered for a repository, 2) development of a repository design and testing of engineering technology as part of system concept development, and 3) performance assessment for the resulting system concept.

Intrinsic Safety Features of the HLW Disposal System Concept

Geological environment

The characteristics of the geological environment that are important for adequate geological disposal must be specified and it must be shown that suitable rock formations with these conditions exist in Japan. Information on host rock properties required to ensure the long-term safety of HLW disposal was compiled via various investigations.

The geological environment has two main functions in terms of ensuring the safety of geological disposal. One relates to the fundamental long-term stability of the site and the other to the properties of the host rock and groundwater which facilitate the emplacement of the EBS and act as a natural barrier. The feasibility of selecting a geological environment in Japan which is appropriate for geological disposal was evaluated based on findings obtained from case studies and field measurements.

First, important natural phenomena which tend to degrade the long-term stability of the geological environment were identified. These include earthquakes and fault activity; volcanic activity; uplift and denudation; and climatic and sea-level changes. The occurrence of these natural phenomena and the extent of changes in the geological environment caused by them were investigated, focusing on the potential effects on the performance of the barrier aspects of the disposal system.

Field case studies were carried out in regions where the long-term results of the natural phenomena mentioned above could be easily observed. The locations and regularity of their occurrence and the extent of any changes were investigated over time scales of several hundred thousand years or more. This work was constrained by variability in the quantity and accuracy of the information, depending on the type of phenomena and the regions involved. These studies showed that the location of localized phenomena, such as volcanic activity and major fault movements, can be well specified and the effects of these phenomena can thus be avoided by selecting an appropriate disposal site. On the other hand, gradual phenomena such as uplift and denudation or climatic and sea-level changes are more ubiquitous. It is, nevertheless, possible to estimate future trends and their potential effects by extrapolating data obtained from these field studies.

Thus, it is possible to select a sufficiently stable environment for geological disposal. For example, there is little possibility that the locations of volcanic activity will change to a significant degree unless there is a major change in the plate tectonic situation. The results of tracing the history of volcanic activity in the Quaternary (i.e. from approximately one million and seven hundred thousand years ago to the present) show that the locations in which volcanic activity occurs are limited to distinct regions and that there is little change in these locations (Fig.1). In addition, the direct effects of volcanic activity are expected to be restricted to within a few tens of kilometers from the activity center at maximum. Significant negative effects from volcanic activity can thus be avoided by selecting disposal sites at a sufficient distant from currently active volcanoes.

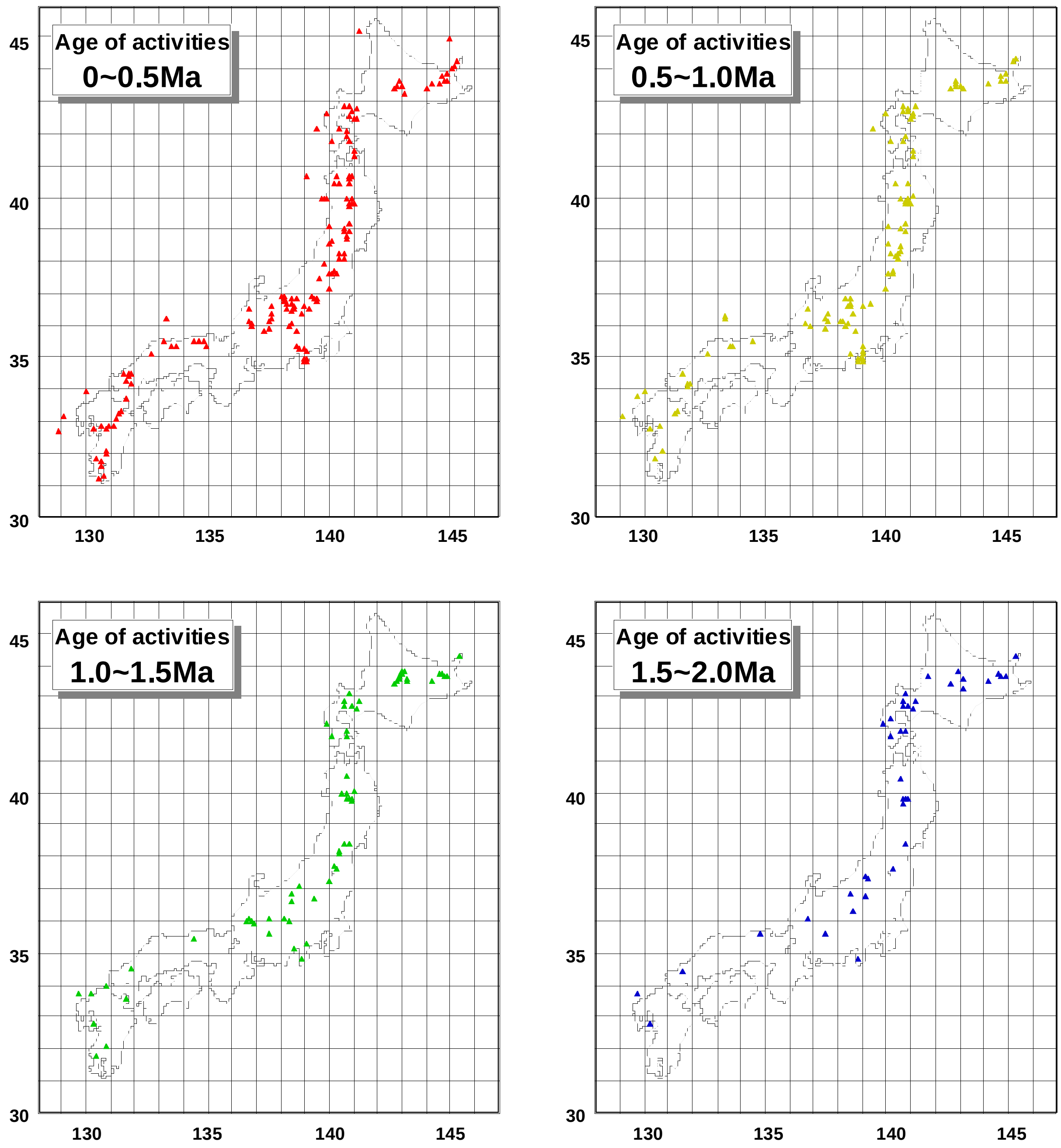


Fig. 1. Quaternary volcanism in Japan
(Grid shows latitude and longitude)

The characteristics of the geological environment which are important in terms of its barrier function include rates of groundwater flow as controlled by hydraulic gradient and permeability, the geochemical characteristics of groundwater, the thermal and mechanical properties of rock formations and solute transport relevant properties. A great deal of data have been obtained on these characteristics, particularly from geoscientific studies carried out in the Tono area and the Kamaishi mine.

Groundwater flow analyses and measurements taken from seven 1,000m deep boreholes in the Tono area show that the hydraulic gradient deep underground is more subdued than the gradient of the topography, being approximately half of that near the ground surface where the gradient is strongly governed by local topographic conditions.

Data in the published literature, taken mainly from the civil engineering field, were compiled in order to investigate the permeability of different rock types. At the same time, these data were compared with measurements taken at several hundred points in the Tono area and the Kamaishi mine. Permeabilities obtained from the literature data were more than an order of magnitude greater than the measurements taken in the Tono area and Kamaishi mine. Excluding fracture zones and fault crush zones, the measured permeability of deep rock formations ranged between 10^{-12} and 10^{-6} m/s, with average values in the order of 10^{-9} - 10^{-8} m/s. Thus it was concluded that a repository located at great depth would likely have very slow groundwater flow and a long pathway from the repository to the accessibly environment providing time for the radionuclides to decay and thus contributing to the intrinsic safety functions of the HLW disposal concept.

Measurements of low-mineralized groundwaters in the Tono area and Kamaishi mine show that water chemistry in Japan becomes strongly reducing deep underground. This phenomenon can be explained by reactions between the groundwater and the major minerals which constitute the rock, clay minerals, microorganisms and organic substances. Reducing conditions contribute to low solubility of radionuclide materials thus limiting the amounts that can be transported by groundwater.

Measurements were carried out as part of the geoscientific studies in the Tono area and Kamaishi mine in order to confirm the initial stress state of the rock. It was found that the ratio between the vertical stress and internal horizontal stress was almost equivalent to 1. It was also found that changes in rock properties caused by tunnel excavation extended to approximately 1 meter from the tunnel wall. The uniform stress field allows easier prediction of stress related changes in tunnel shape with time and the limited excavation disturbance helps to limit negative impacts on either construction safety or prediction of long-term migration of radionuclides.

Pore structures observed in numerous mines and tunnels were investigated in order to clarify the mechanisms of underground solute transport. Observations and test results from the Kamaishi mine and Tono area showed that fractures developed in crystalline rocks and old sedimentary rocks provide the major transport pathways. On the other hand, interparticular pores and microfractures provide the major transport pathways in recent sedimentary rocks. It was also confirmed that clay minerals and ferrous minerals, such as mica and pyrite, display generally higher radionuclide sorption than quartz and feldspar. While groundwater transport will occur, it will be slow as describe above and the interaction of flowing water with the adjacent rock will allow radionuclides to be sorbed as they are transported along the discrete fracture pathways. This sorption retards the migration rate and allows longer time for radioactive decay thus contributing to the barrier functions of the geosphere. The presence of clay minerals in certain environments would accentuate this process.

The above findings led to the conclusion that the deep geological environment can maintain the integrity of the EBS for a long period of time and that the strata themselves can function as a natural barrier.

Repository design and engineering technology

The design requirements for the EBS and the disposal facility in general were clarified based on currently available technologies while considering the wide range of geological environments throughout Japan and the desire for intrinsic repository performance. Realistic and reliable data and analysis techniques were used in order to derive specifications for the EBS design and the other components of the disposal facility that would provide robust radionuclide control. These specifications also took economic aspects into consideration to some extent.

Since the publication of the first progress report, more reliable supporting data have been obtained from demonstration tests on both a laboratory and an engineering scale. The demonstration tests were carried out as part of studies performed at JNC's ENTRY facility (Masuda et al., 1994), geoscientific studies in the Tono area and Kamaishi mine, international joint research activities at underground research laboratories abroad and studies at research facilities both in Japan and abroad (Masuda et al., 1996). The design requirements have been reviewed; analysis techniques which provide tools for the design have been improved and the database for the design has been developed in order to more fully understand the barrier characteristics of the engineered system.

Data collected mainly from published literature were compared with the findings obtained from in situ studies carried out in the Tono area and the Kamaishi mine. The practical feasibility of designing and emplacing the EBS and the disposal facility was clarified for a wide range of physical rock properties. This has provided a basis for the design and construction plan for the EBS and disposal facility which is robust enough that it can be tailored to the specific characteristics of a potential disposal site in the future and yet provide a large degree of control on radionuclide release.

The impact on barrier performance of EBS specifications, such as selection of materials and the thickness of the overpack and buffer, were investigated and the results of preliminary calculations were used to modify the design requirements. According to the calculations, the thickness of both the overpack and buffer materials could be reduced by approximately 30%, compared with the specifications indicated in the H3 (Fig.2). This leads to about 50% reduction of total volume of the EBS materials. Bentonite mixed with quartz sand was selected as the buffer material, which would bring about a reduction in costs. Both of these changes can be implemented without a significant increase in the level of radionuclide releases.

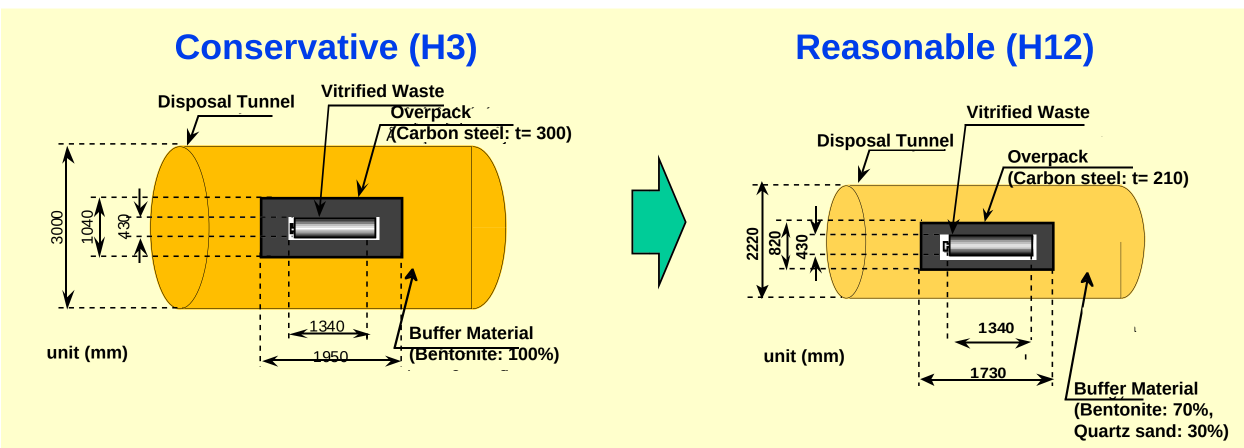


Fig. 2. Improvement of EBS design

The mechanical stability of tunnels was investigated based on data obtained from relevant geological environments. Rough estimates were then made of the depth range in which construction of the disposal facility is feasible. In addition, a design concept for efficient emplacement of the vitrified waste and layout of the tunnels was developed based on thermal analyses. It was shown that the specifications of this EBS will allow construction of the disposal system, emplacement of the waste forms (i.e. operation of the facility) and backfilling of the tunnels (i.e. closure of the facility) using currently available technologies or technological advances which are expected in the near future. Development of more reliable technologies is ongoing and it is also expected that the applicability of the engineering technologies will be further evaluated as part of the experiments planned for future deep underground research facilities in Japan.

This combination of engineering design studies shows that the intrinsic safety features of the repository design can be maintained and balanced against economic concerns. In addition, demonstrating that emplacement is feasible gives confidence that the repository can be safely constructed and that the resulting construction will be of very high quality (largely free of defects in workmanship) which would affect its barrier functions.

The Guidelines require the H12 report to discuss basic concepts for management of the disposal site during the period from repository construction, through operation to final closure. One objective of the management of the disposal site is to collect and assess technical information to support decisions concerning permanent closure of the repository. In addition, monitoring the effects of repository construction and operation on the geological environment as well as assessing the quality of emplacement of the engineered barriers are primary elements of the operational phase management. Given the focus on collection of technical information concerning long-term performance and the quality assurance monitoring, the main components of management during operation and suggestions for the connection between monitoring and decisions related to closure/retrievability were discussed.

Performance Assessment to Illustrate Robustness of the Disposal System Concept

Approach

While the main safety features of the repository are intrinsic to the design and location within a deep geologic system, understanding the level of robustness of the proposed system in various geologic settings or under changes in system conditions can only be evaluated through predictive studies of long-term repository performance. An assessment method which allows reliable evaluation of the safety functions of the geological disposal system under various conditions was developed and an integrated analysis for the above system concept was carried out using this method.

A systematic approach was adopted for defining scenarios. Firstly, a comprehensive list of FEPs (features, events and processes) was prepared. The FEPs were reviewed for relevance and grouped into scenarios, namely sets of isolation failure scenarios and groundwater scenarios.

Natural events and human activities that could trigger isolation failure scenarios were identified. It was demonstrated that selecting an appropriate site can reduce the possibilities of these initiating events. To provide input to future site selection, a set of “what if” analyses were carried out for these scenarios.

In contrast, groundwater scenarios are reasonably likely to occur in the future. Furthermore, a large number of FEPs contribute to migration of soluble radionuclides from the repository, resulting in a much wider spectrum of possible future evolutions of the system. In order to explore the spectrum of groundwater scenarios, a reference case is first defined to assess the performance of a reference system in the context of a base scenario where external events would be considered not to affect the intrinsic safety of the repository (Fig.3). In the reference case, the geological disposal system is characterized by realistic data from the geological environment and the specifications of the EBS, which represent the design parameters. In addition to the reference case, a number of alternative cases were analyzed to address uncertainties in models and data, alternative geological disposal systems, and perturbation scenarios arising from natural events and human activities.

Based on a list of feasible and important scenarios, models which simulate relevant phenomena in detail together with associated databases were established in order to quantify selected scenarios. Models were developed to simulate the evolution of the EBS and subsequent radionuclide migration in the rock surrounding the buffer material. These models are more detailed and realistic than those used in the H3 assessment and thus improve our understanding of key processes. The same can be said of the corresponding databases.

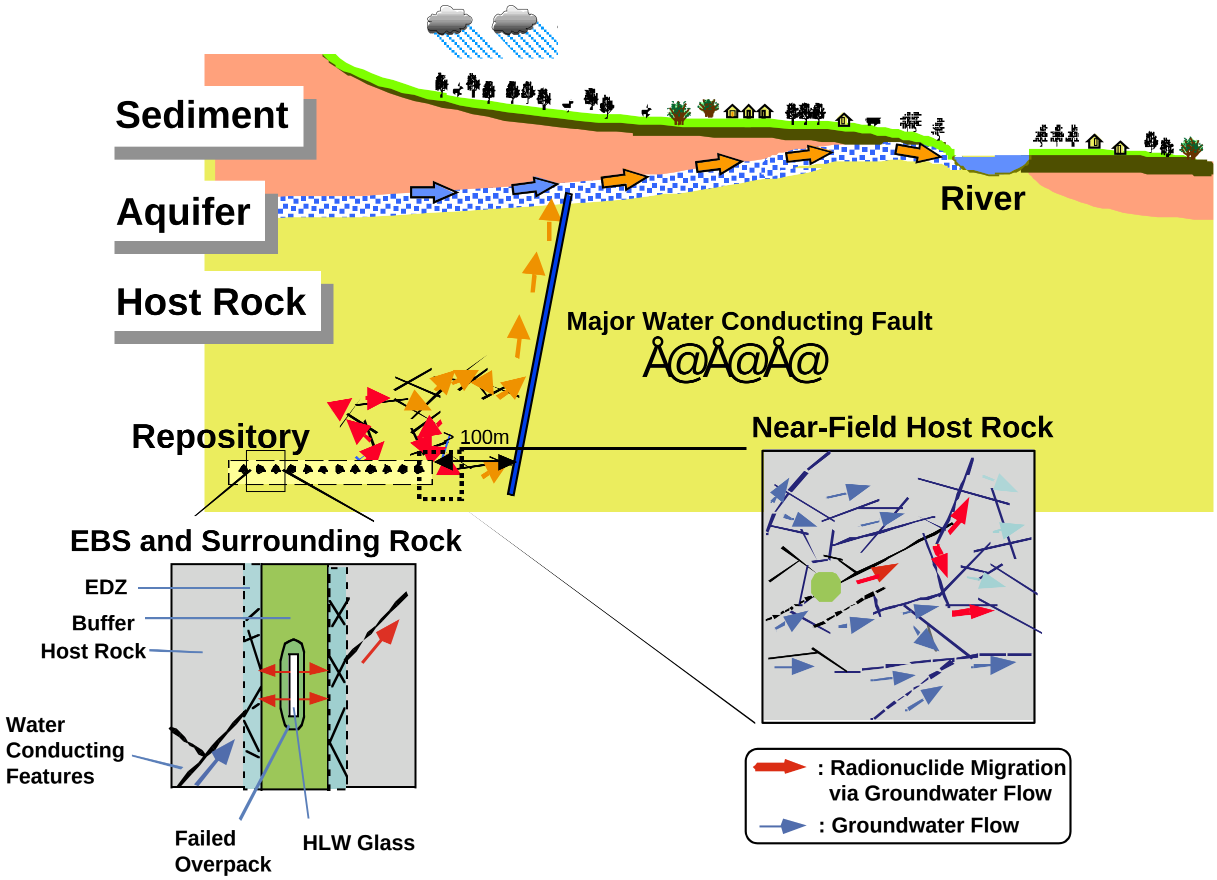


Fig. 3. Groundwater scenario reference case and conceptual models for radionuclide migration

The main transport model used to represent EBS performance is based on one-dimensional, diffusive transport with linear, reversible and instantaneous sorption. Shared solubilities and precipitation of each radionuclide are also considered for chain-migration process through the buffer. The long-term dissolution rate obtained experimentally for glass dissolution is used at the waste glass-bentonite interface. Radionuclides are assumed to be congruently dissolved with glass and limited in their release by solubility at the glass surface. The radionuclides released at the outer boundary of the buffer are assumed to be instantaneously mixed within the excavation disturbed zone and distributed among fracture pathways in proportion to each pathway's individual water-flux.

To assess geosphere performance for the host rock surrounding the repository, the multi-one-dimensional model, which is computationally highly efficient, was used in the modeling of transport through the host rock. In this model, advection-dispersion in individual fractures, matrix diffusion, sorption onto surfaces within the rock matrix and radioactive chain decay are taken into account. A three-dimensional heterogeneous channel network model was also developed to investigate the adequacy of the simplified assessment model. Within this detailed simulation approach, a stochastic discrete fracture network model defines a system of transport paths that are constructed by linking the intersection of fractures along each fracture plane. Radionuclide transport is then simulated along the interconnected set of channels taking into account advection-dispersion in individual fractures, matrix diffusion, sorption onto surfaces within the rock matrix and radioactive chain decay. It was found that the model results for the network could be closely approximated by the superposition of several, one-dimensional models, representing multiple pathways.

Radionuclide releases from the various canisters are assumed to flow towards a single, major water conducting fault located in the downstream from the repository. All radionuclides released from the waste packages of vitrified waste in the repository are assumed to migrate upwards through the fault for 800 meters to a shallow aquifer which in turn discharges to a river. Significant dilution occurs as a small amount of groundwater from the aquifer enters the river. The retardation effect and traveling time in the fault are included in the performance assessment but are conservatively ignored for the aquifer.

Radionuclides released into the biosphere are modeled based on a reference biosphere methodology. The biosphere model represents the components of the surface environment using compartments between which fluxes of material (solid/water) and radionuclides are defined by transfer factors. A range of exposure pathways via which such radionuclides could enter the food chain, along with uptake and concentration factors, are also defined. The resulting dose (from both ingestion and external irradiation) to a hypothetical critical group is then calculated. Parameters describing the processes in this system are based on estimates of present-day environmental and lifestyle conditions.

Assessment Results

These models mentioned above were linked with one another in a safety assessment model chain, which allows the performance of the entire geological disposal system to be assessed. The reference case was analyzed using this model chain. The results were compared with results obtained using analysis codes developed by other organizations in order to confirm that the safety assessment methods correctly perform its intended functions.

The basic model chain mentioned above performs calculations for a repository containing 40,000 packages of vitrified waste. The calculation result for the reference case indicates sufficient confinement of radionuclides can be achieved by the EBS and the near-field host rock, provided that the groundwater flow rate is reasonably low (Fig.4).

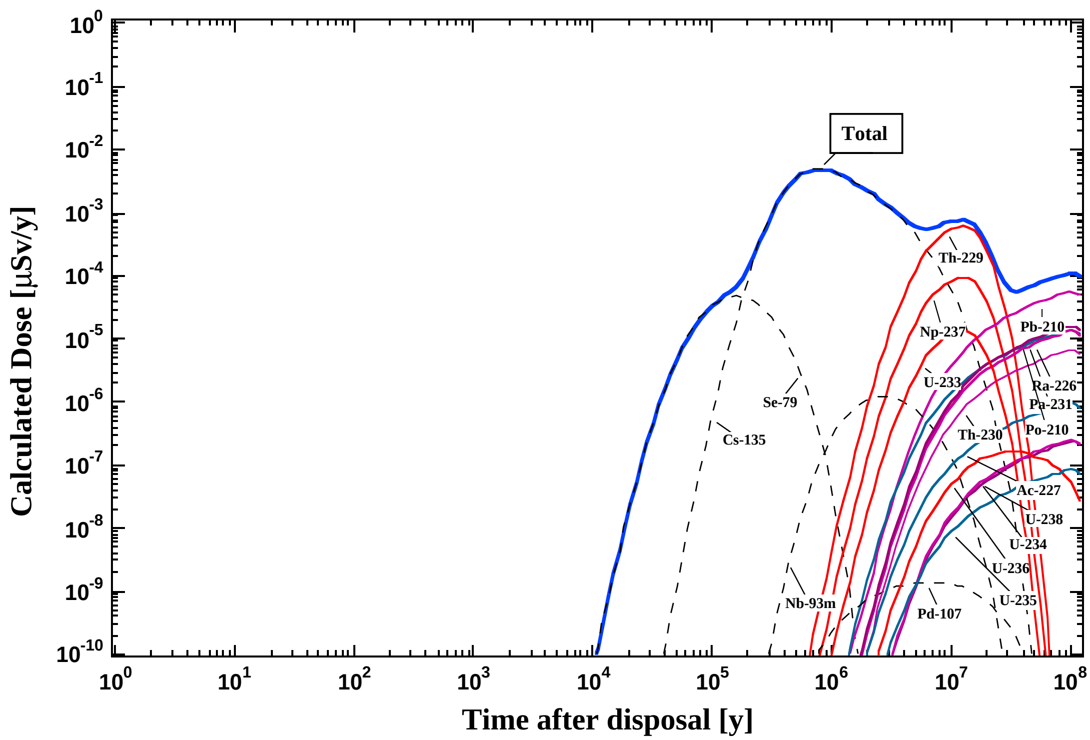
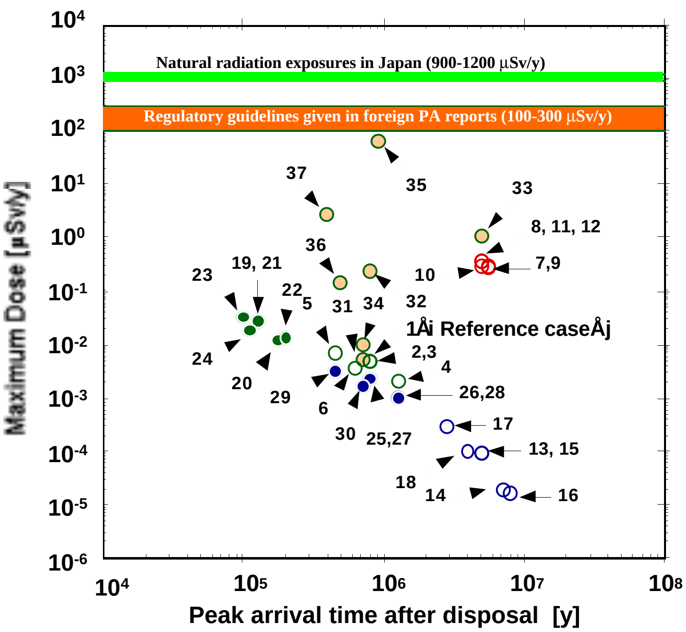


Fig. 4. Example of dose evaluation for a repository containing 40,000 packages of vitrified waste
(all packages are assumed to fail at 1,000 years after disposal)

Model and data uncertainty cases were analyzed by considering a wide range of alternative models and parameter values. The results indicate that the most important parameters are the groundwater flow rate, groundwater type, and the rock matrix retardation parameters. In addition, a number of calculation cases have been conducted for perturbation scenarios in which the geological disposal system is perturbed in the future by natural events and human activities.

Based on the understanding of sensitivity structure acquired through these numerous calculations, a set of cases focusing on the key factors has been analyzed for all the self-consistent combinations of alternative geological environments and designs. Due to effects of uncertainties in models and data, alternative disposal systems, and unlikely disruptive events, calculated values of the maximum annual dose vary significantly. However, none of them exceed the radiological protection levels proposed in the foreign regulatory criteria or guidelines (100 - 300 μSv/y) (Fig.5).



Calculation cases	Case No.	Difference from Reference case: Groundwater	Hydraulic gradient	Rock type	GBI
Reference case	1	Freshwater High pH	0.01	Silicic crystaline rock	River water
System variability	2			Mafic crystaline rock	
	3			Pre-Neogene sandstone	
	4			Pre-Neogene mudstone & tuff	
	5			Neogene sandstone	
	6			Neogene mudstone & tuff	
	7		0.1	Silicic crystaline rock	
	8			Mafic crystaline rock	
	9			Pre-Neogene sandstone	
	10			Pre-Neogene mudstone & tuff	
	11			Neogene sandstone	
	12			Neogene mudstone & tuff	
	13		0.001	Silicic crystaline rock	
	14			Mafic crystaline rock	
	15			Pre-Neogene sandstone	
	16			Pre-Neogene mudstone & tuff	
	17			Neogene sandstone	
	18			Neogene mudstone & tuff	
	19	Saline High pH	0.01	Silicic crystaline rock	Marine sediments
	20			Mafic crystaline rock	
	21			Pre-Neogene sandstone	
	22			Pre-Neogene mudstone & tuff	
	23			Neogene sandstone	
	24			Neogene mudstone & tuff	
	25		0.001	Silicic crystaline rock	
	26			Mafic crystaline rock	
	27			Pre-Neogene sandstone	
	28			Pre-Neogene mudstone & tuff	
	29			Neogene sandstone	
	30			Neogene mudstone & tuff	
	31	Buffer thicknessÅi 0.7 m => 0.4 mÅj			River water
	32	GBI (River water => Deep well)			Deep well
Data uncertainty	33	Taking account of uncertainties on glass disolution rate, Kd in rock and hydraulic conductivity			River water
Model uncertainty	34	Taking account of transport with groundwatr colloids			
Scenario uncertainty	35	Uplift and erosion (rate = 1.0 mm y^{-1}Åj			
	36	Transport in tunnels and shafts due to plug/sealing failure			
Robust case	37	Modified geosphere model (immediate transport to biosphere)			

Fig.5 Results of total system performance analysis:
(Plot of maximum dose - peak arrival time)

As dose estimates inevitably include significant uncertainties from biosphere modeling, supplementary safety indicators have been investigated. For example, it has been shown that comparison of radionuclide concentrations calculated at several positions in a disposal system, with concentrations of naturally occurring radionuclides, provides a useful perspective on repository safety.

The methodology developed in the H12 program provides a basis for the performance assessment of a geological disposal system at a site to be selected in the future. At the site-specific stage it will be important to incorporate realistic geological features and optimized engineered barriers without compromising the robustness and conservatism in the methodology that are essential to a reliable assessment.

Conclusions

In summary, the concept of deep geological disposal of HLW in Japan appears to be technically feasible and the research effort described in the H12 report shows with more reliability and confidence than H3 the robustness of the conceptual system. The major results of R&D activities that support increased confidence in the disposal concept can be summarized as follows:

- The location and scale of natural phenomena, such as volcanic activity, faulting and crustal movement have been traced over approximately the past several hundred thousand years by conducting appropriate case studies and analyzing the latest information available through scientific literature and conferences. The fact that the level and accuracy of information vary somewhat for different types of phenomena and geographical regions is taken into account. Based on the results of these studies, it can be shown that it is possible to select a sufficiently stable geological environment in Japan such that a repository will not be influenced by disruptive natural phenomena for around the next hundred thousand years. Databases on the properties of rock formations and deep groundwater have been extended to include the latest scientific information available in the literature. Data from measurements in the Tono region and in the Kamaishi Mine have also been included to refine understanding of processes and enhance the credibility of the databases. Based on these revised databases, it can be confirmed that the deep geological environment is generally suitable as a natural barrier and as an environment for construction, thus supporting the long-term performance of the EBS.

- In order to reduce the degree of conservatism and thus cost in implementing the EBS and the disposal facility as a whole while maintaining sufficient levels of robustness and safety for a wide range of geological environments, the volume of the EBS material has been reduced by up to 50% when compared with similar designs in the H3 report. At the same time, this design still provides sufficient robust behavior in its intrinsic radionuclide control functions. Fabrication tests, engineering-scale tests and in-situ testing have shown that it is possible to construct the EBS and the repository with a reasonable investment of effort and cost using conventional engineering technologies. Thus, the intrinsic functions of the repository are not likely to be compromised by construction defects.

- To illustrate and evaluate for various environments the robustness of the long-term safety of the disposal system, a methodology for safety assessment has been developed which focuses on the performance of the near field. This methodology consists of developing relevant scenarios and realistic models, along with assimilating data with a view to evaluating the overall safety of the system. Using these models and databases, a performance assessment has been conducted for the groundwater scenario reference case, which takes into account the requirements set down by the AEC Guidelines. The models were implemented in a realistically conservative manner and thus represent some degree of robustness in their resulting estimates. The results show that the risks at the time of maximum influence on man are considerably below the levels of foreign standards currently in force.

The results of these various R&D activities have been integrated as part of developing a safety case within the H12 report to demonstrate the technical reliability and safety of the geological disposal concept. The basic defense that the proposed repository system is safe is supported by the functions intrinsic to the design including barrier aspects of the engineered system, stability and barrier aspects of the naturals system and so forth. The robustness of long-term performance of the system in various geologic settings is then illustrated through detailed numerical simulations as part of performance assessment.

These studies are also expected to provide a technical and scientific basis for the site selection process and for developing a regulatory framework.

Reference:

The Atomic Energy Commission of Japan (1994): Long-Term Program for Research, Development and Utilization of Nuclear Energy.

The Advisory Committee on Nuclear Fuel Cycle Background Policy, The Atomic Energy Commission of Japan, (1997): Guidelines on Research and Development Relating to Geological Disposal of High-level Radioactive Waste in Japan.

JNC (1999a): H12 Project to Establish Technical Basis for HLW Disposal in Japan, Project Overview Report on Research and Development for the Geological Disposal of HLW in Japan, JNC TN1400 99-020 (in Japanese).

JNC (1999b): H12 Project to Establish Technical Basis for HLW Disposal in Japan, Supporting Report 1 on Research and Development for the Geological Disposal of HLW in Japan, Geological Environment in Japan, JNC TN1400 99-021 (in Japanese).

JNC (1999c): H12 Project to Establish Technical Basis for HLW Disposal in Japan, Supporting Report 2 on Research and Development for the Geological Disposal of HLW in Japan, Repository Design and Engineering Technology, JNC TN1400 99-022 (in Japanese).

JNC (1999d): H12 Project to Establish Technical Basis for HLW Disposal in Japan, Supporting Report 3 on Research and Development for the Geological Disposal of HLW in Japan, Safety Assessment, JNC TN1400 99-023 (in Japanese).

PNC (1992): Research and Development on Geological Disposal of High-level Radioactive Waste, First Progress Report - H3, PNC TN1410 93-059.

Masuda, S., Yamakawa, M., Umeki, H., Miyahara, K. and Naito, M. (1998): High-level Radioactive Waste Disposal in Japan: Research and Development Programme, Proc. Waste Management'98, Tucson.

Masuda, S., Ishiguro, K., Yui, M. and Mano, T. (1994): Core Message from PNC/H-3 and Key Issues for the Next Milestone, Proc. The Fifth Ann. Int. Conf. High Level Radioactive Waste Management, Las Vegas,.

Masuda, S., Yamakawa, M. and Umeki, H. (1996): Role of International Collaboration in PNC's R&D Programme for HLW Disposal, Proc. SPECTRUM'96, Seattle.